MODEL STUDIES

OF

APRA HARBOR, GUAM, M.I.

PROGRESS REPORT for JUNE, 1948

CALIFORNIA INSTITUTE OF TECHNOLOGY
Hydrodynamics Laboratories, Hydraulic Structures Division

Operating Under

Contract NOy-12561 United States Navy Department

Contract NOy-12561
U. S. NAVY DEPARTMENT
BUREAU OF YARDS AND DOCKS

MODEL STUDIES
of
APRA HARBOR, GUAM, M.I.

PROGRESS REPORT
for
JUNE 1948

HYDRODYNAMICS LABORATORIES
HYDRAULIC STRUCTURES DIVISION
of the
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena 4, California

Robert T. Knapp
Director

Vito A. Vanoni
Associate Director

Report Prepared
by

Warren O. Wagner
Project Supervisor

July 1, 1948

THE COVER . . . .

shows the current pattern in the outer harbor as determined by photographing at four second intervals reflecters floating on the water surface. The currents present here are those induced by westerly waves 30 feet high and 1200 feet long. For further details on the technique and interpretation see the text.

TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

I INTRODUCTION

Studies of induced currents were the main activity of the month. Preliminary frequency response studies were started and detailed marigram analysis was resumed.

Studies of induced currents involved development of methods, running of tests and analysis of data. Some currents are induced in the harbor by the waves which pass through the entrance. These were the currents studied. They give basic data. Tidal changes and outer ocean currents will be superposed later to learn of composite effects.

Frequency response studies were initiated this month also. The present wave machines were designed to make such tests possible, since both amplitude and frequency of the wave trains can be controlled over wide ranges. It is intended to run tests through the entire spectrum after observing and measuring the effects of certain calculated frequencies. The calculated frequencies were the fundamentals and harmonics of each division of the harbor.

Marigram analysis was resumed along the lines of the program previously decided upon, i.e. computation and plotting of residual mass curves between adjacent stations. These curves reveal the duration and rate of flow which could obtain through the proposed pollution channels.

Modification to the oscillograph was made to reduce the tape speed, the range in speeds being broadened accordingly. Component parts of the wave height averaging device are being assembled as received.

II SCOPE OF REPORT

This report is concerned primarily with currents induced in the harbor by waves passing through the entrance. These basic findings will be of value in interpreting the effects of tidal changes and outer ocean currents when included later. Ocean conditions used were westerly waves 30 feet high, 600 and 1200 feet long at MHHW.

The current directions and speeds found are presented graphically and discussed in detail. The test procedure adopted is outlined and a complete description of the equipment used is given.

III INDUCED CURRENT STUDIES

A. General

The induced current studies made to date are a preliminary part of the main study of the conditions that will affect the pollution of the harbor. The currents within the harbor at Guam are the combined effects of the ocean currents which flow offshore, the imposed waves, and the tides. In the model it was considered advantageous, however, first to isolate and study the patterns of the currents induced by waves only. Studies of the effects of offshore currents and of the tides are contemplated later so that each of the three components may be properly evaluated.

The currents discussed here are surface currents and have been induced by westerly waves, 30 feet high, 600 and 1200 feet long with inner breakwater D-2 in place. The overall patterns are somewhat similar for the two wave lengths, and yet they differ appreciably in specific areas. See Fig. 1 (page 9).

Subsurface currents are also present. These are determined by adding small amounts of dye in the regions to be observed. As yet these subsurface currents have not been studied extensively enough to warrant inclusion in this report.

Reflecting floats, to be described later, are distributed in the area under consideration and photographed to obtain a measure of the currents. The distance travelled by each float in a given time measures the average speed of the current. Visual observation has shown, however, particularly in regions of apparently strong current, that the floats travel with "jerky" motions, i. e. they travel fast one instant and slow the next. This is because the oscillatory motion of the waves is superimposed on the steady flow of the currents. For the same wave height, the magnitude of the horizontal component of this oscillatory motion increases with decreasing depth. It is therefore felt that the speed of the floats as measured from still photographs is not truly indicative of the speeds of the currents, particularly in shallower regions of the harbor.

B. Directions of Currents

Several pronounced currents cover rather extensive areas. One, having a completely closed clockwise circuit as shown by float movements, has a part of its circuit extending along the inner side of the breakwater.

It is interesting to note that this current extends out past the terminus approximately one third of a mile in one direction and as far as Pier D in the other. When the current is due to waves which are 600 feet long the southerly leg of the circuit roughly parallels the northerly leg. With 1200 feet long waves the current continues to flow south from the vicinity of Pier D, traveling along the greater part of the north-south axis of the harbor. It then turns northwesterly, making a reverse curve before reaching the breakwater entrance and completing its circuit out beyond the terminus.

INDUCED CURRENTS IN OUTER HARBOR AND REPAIR BASIN

BY WESTERLY WAVES 30 FEET HIGH AT MHHW

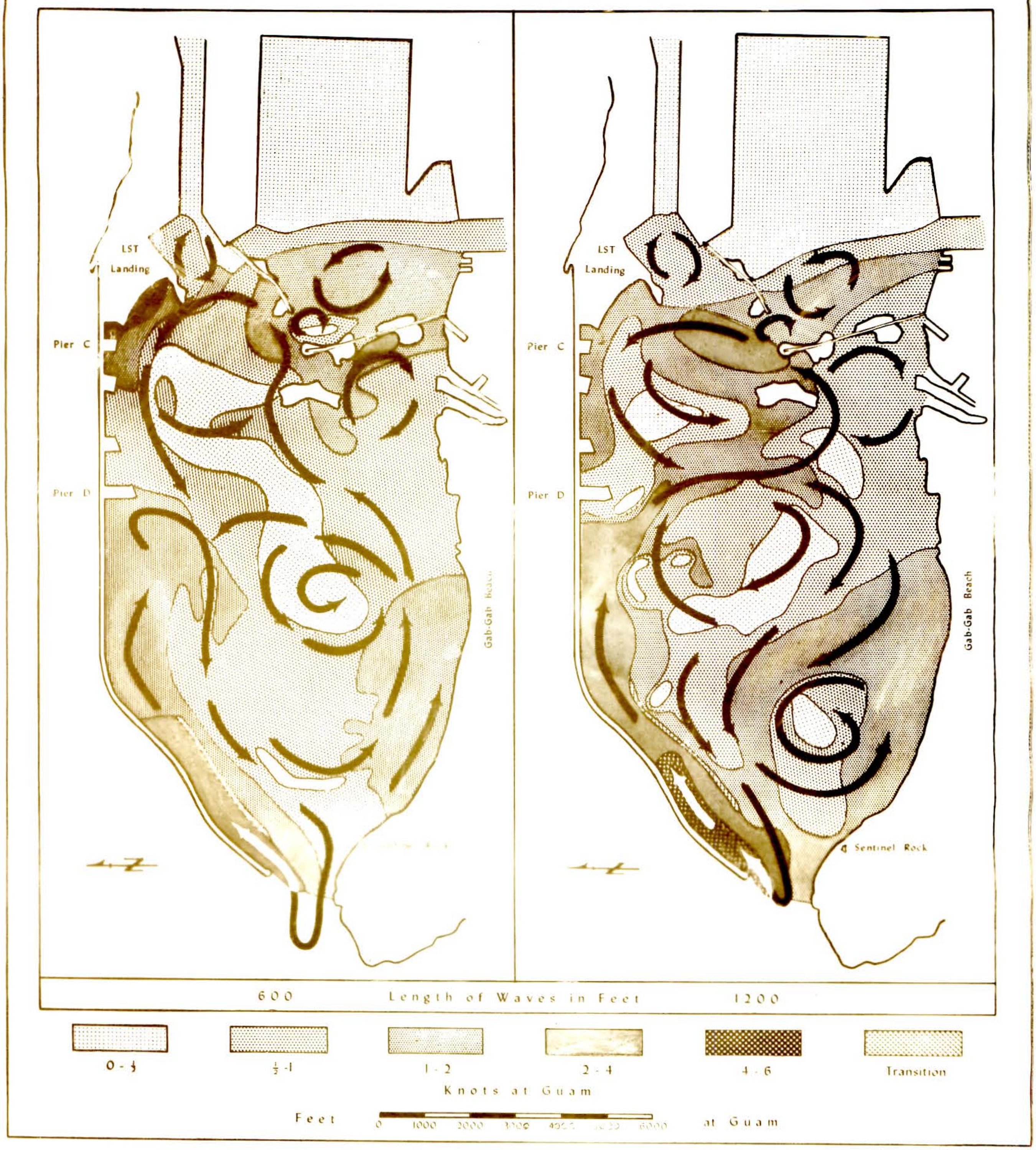


Fig. 1

There is quite a difference in the patterns of the other currents for the two wave lengths, as can be seen in Fig. 1. The behavior of the currents due to waves 600 feet long will be described first.

The area roughly west of a north-south line through Pier D with the exception of the area occupied by the current just discussed, is traversed by counter-clockwise currents which coincide in the northern part of the area with the clockwise outgoing current for about three-quarters of a mile. The counter-clockwise current is very noticeable in the area north of the shoreline between Gab Gab Beach and Sentinel Rock.

A second large area of counter-clockwise currents exists east of Pier D and roughly north of Western Shoal, extending east to about the southwesternmost part of the land area of the LST Landing. Clockwise currents can be noted in the LST Landing area and just south of Western Shoal while a counter-clockwise current occurs in the outer portion of the repair basin.

Dye placed in the water at the harbor entrance shows a seaward subsurface current through the south portion of the entrance.

For waves 1200 feet long a minor clockwise path occurs within the eastern portion of the area enclosed by the current first described. Another major counter-clockwise current is present extending from west of Western Shoal nearly to the LST Landing, skirting Western Shoal on the south and the breakwater on the north. As with waves 600 feet long clockwise currents are found in the LST Landing area and south of Western Shoal and a counter-clockwise current is observed in the outer portion of the repair basin. A counter-clockwise current is noted in the area inward from Sentinel Rock.

The paths of the currents induced by either wave length are fairly well reproducible. The overall behavior of the currents might best be pictured by considering them to act much as a train of meshed gears.

Zones throughout which currents are of approximately equal magnitude are distinctively cross-hatched.

It should be pointed out here that each of the two charts in Fig. 1 is a composite of two successive runs, each having a two hour prototype duration.

Figures 2 and 3 (pages 15 and 19) show the photographs used in the determination of the currents discussed herein. The left halves of these plates show currents induced by waves 600 feet long while currents due to waves 1200 feet long are portrayed on the right halves to correspond with the two parts of Fig. 1.

C. SPEEDS OF CURRENTS

1. General

In Fig. 1 the harbor area is zoned to indicate the current speeds predominating. Six zones are used, namely

0 to 1/2 knot

1/2 to 1 knot

1 to 2 knots

2 to 4 knots

4 to 6 knots

transition zone

The transition zone is an unstable region where currents travel in either direction with varying strengths. Table 1 lists the areas of each zone as a percentage of the total harbor area as shown in Fig. 1.

Table 1

EXTENT OF ZONES OF EQUAL CURRENT SPEED
AS PERCENTAGES OF TOTAL AREA

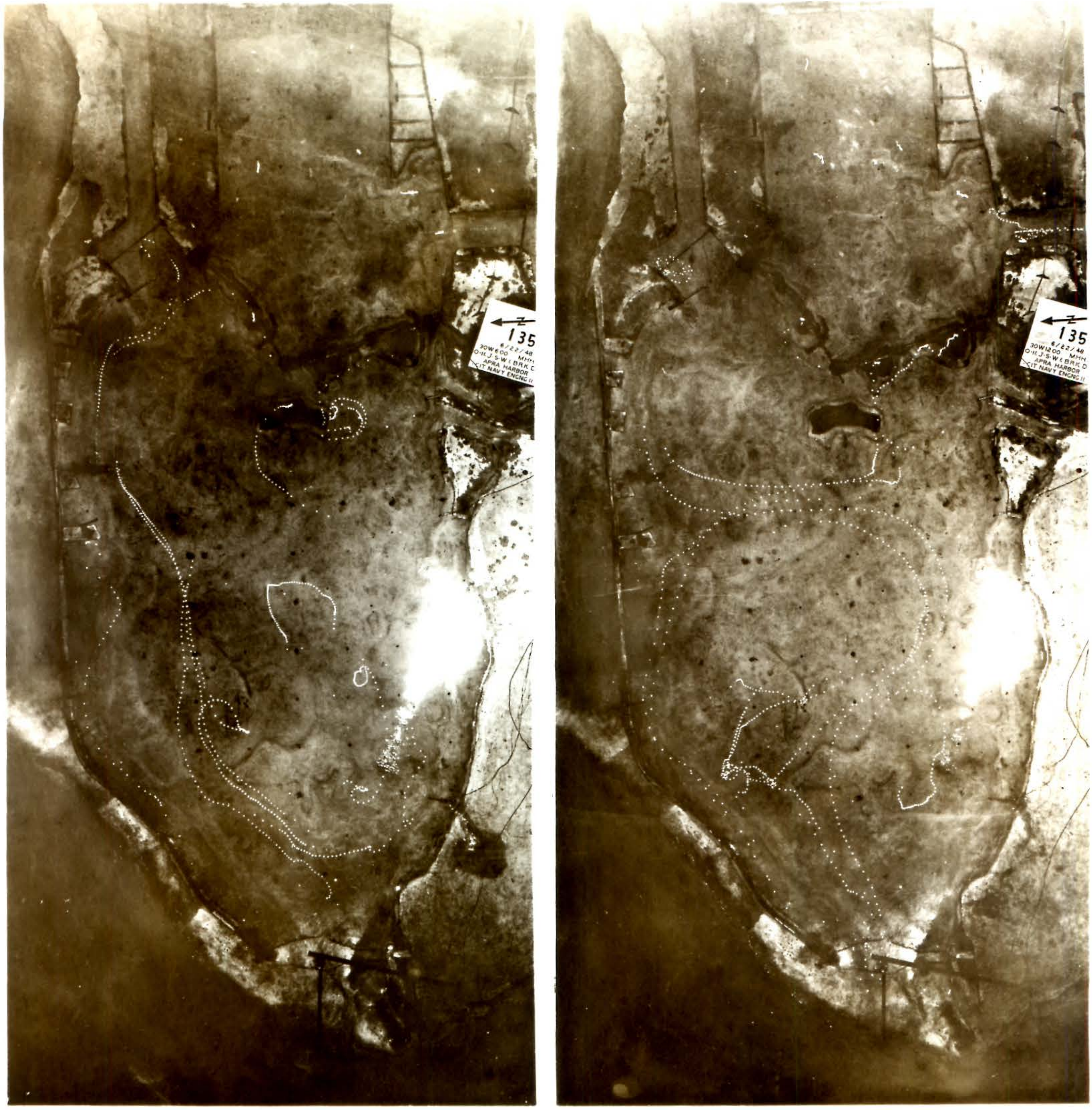
Waves 30 feet high

Speed Range (Knots)	Length of Waves Inducing Currents 600 feet	1200 feet
Transition	nil	nil
0 - ½	26.3%	27.7%
½ - 1	38.1	30.0
1 - 2	31.1	29.4
2 - 4	4.5	11.1
4 - 6	0.0	1.8
Total	100.0%	100.0%

Fig. 2

The photographs on the opposite page are an indication of the currents induced in the outer harbor and repair basin by westerly waves 30 feet high. The white dots are reflections from lights (near the camera lens) on moving floats on the water surface. Every four seconds, except at the beginning of a test run, the camera shutter is opened for 1/300 second during which time the lights are flashed. The spacing between dots is the distance the floats have traveled in four seconds. The farther apart the dots are spaced, the faster the current. At the beginning of a test run the interval is 10 seconds, thus providing a means of determining the start of each trace. Movement in the repair basin is remarkably slow compared to that in the outer harbor. It was from these photographs and those in Fig. 3 that Fig. 1 was derived.

The bright spot in the center right of each photograph is the reflection from the water surface of the light used in the camera tower to illuminate the reflecting surface of the floats.



Waves 600 ft. long

MHHW

Waves 1200 ft. long

Float Traces Showing Currents Induced By Waves

During A Two Hour Run

Westerly Waves 30 Feet High

Fig. 2

The average current speed over the entire outer harbor and repair basin is 20% higher with waves 1200 feet long than with waves 600 feet long. Also the extent of the 2 to 4 knot zone with waves 1200 feet long is $2\frac{1}{2}$ times that with waves 600 feet long. All other zones are about equal in area for the two wave lengths, except for a decrease in the 1/2 to 1 knot zone to counteract the increased 2 to 4 knot zone. The speed of wave-induced currents in the larger portion of the inner harbor appears to be unaffected by changes in wave length.

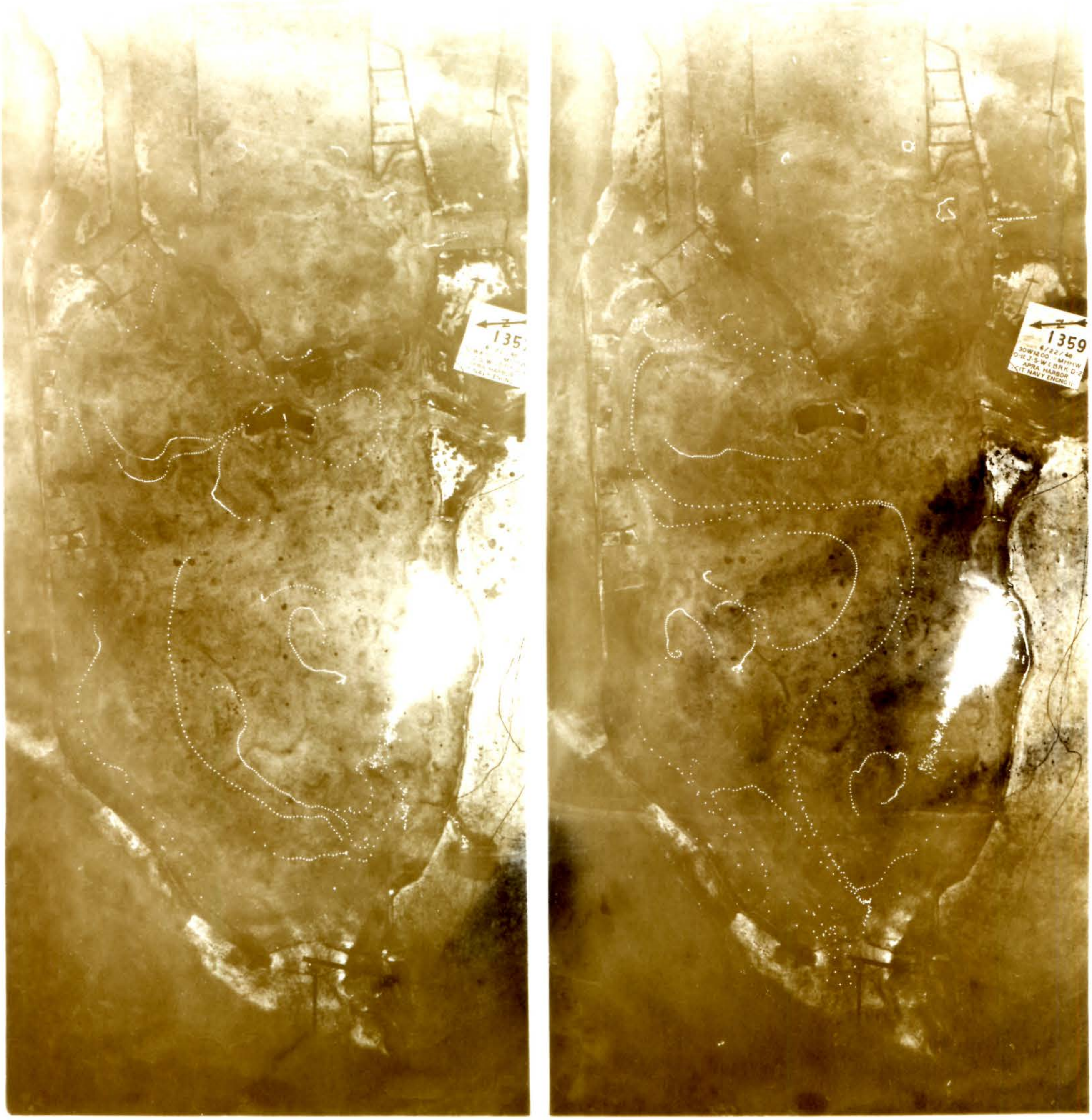
2. Currents Induced by Waves 600 Feet Long

There are two major zones having speeds between zero and 1/2 knot. One is the eastern portion of the repair basin and the other extends southwesterly from the vicinity of Pier C for about $1\frac{1}{4}$ miles. Small areas of the same speed range are found near the northern of the two southern shoals, in the eastern reaches of the LST landing, in the channel north of the Navy fleet landing and about 1/3 mile due east of the existing breakwater entrance.

The zones of 1/2 to 1 knot and of 1 to 2 knots dominate throughout the outer harbor. The lower speeds are found in the west central portion of the harbor, fanning out towards the east and surrounding the zero to 1/2 knot region of the outer harbor. The 1 to 2 knot zone is encountered close to the breakwater entrance along the boundaries and in the area surrounding Jade, Southern and Western Shoals, in addition to a small area along the shore line west of the LST landing. In the center of the outer harbor, lower speeds are encountered than along the shores

Fig. 3

These photographs are for a two hour prototype period similar to those in Fig. 2. Attention is called to the similarity of the pictures on the left of each figure and to the similarity of the pictures on the right of each figure. Although the reflector floats were not placed in the water at the same points the patterns are remarkably reproducible for the same wave length. The pattern for the two wave lengths is not the same, however.



Waves 600 ft. long

MHHW

Waves 1200 ft. long

Float Traces Showing Currents Induced By Waves

During A Two Hour Run

Westerly Waves 30 Feet High

Fig. 3

or the breakwater. This is to be expected because the wave form in the deeper water is more symmetrical and the floats have more tendency to follow the orbit set by the waves.

Speeds between 2 and 4 knots were measured for about two-thirds of a mile in the lee of the southwest end of the breakwater. A small area of this speed range is found also between the two Southern Shoals.

A transition zone is present in the vicinity of the southwest end of the breakwater. Here the current is of varying strength and moves first in one direction and then the other.

3. <u>Currents Induced by Waves 1200 Feet Long</u>

The pattern of speed distribution appears considerably more complex with currents induced by waves 1200 feet long than by waves 600 feet long. The areas in the outer harbor are far less coherent and the range between zero and one half knot particularly is scattered quite widely.

The locations of the zones for speeds between 1/2 and 1 knot and between 1 and 2 knots are roughly analogous to those with waves 600 feet long. The area of the range between 1/2 and 1 knot is smaller with this wave length than with waves 600 feet long. The area for the 1 to 2 knot range is fully coherent extending from the breakwater entrance to, and including, the shoal area.

The area between 2 and 4 knots is considerably larger than with waves 600 feet long. It begins at the breakwater entrance and extends to Pier D in a fairly wide band. There is a sizable area also between Western Shoal and the LST Landing.

An additional range, 4 to 6 knots, is found with the greater wave length. It is in the immediate lee of the southwest end of the breakwater and is comparable in extent to that of the 2 to 4 knot zone with waves 600 feet long.

A transition zone similar to the one with 600 feet long waves exists here also.

It can be seen that high current velocities seem to exist in the lee of outer breakwater with waves either 600 or 1200 feet long. As has been pointed out in section IIIA it is doubtful if the currents in these shallow areas are as large as reflector movements indicate.

The reliability of the data on the whole is good. It is expected that it will be further improved by minor changes in the test procedure.

D. EQUIPMENT USED IN INDUCED CURRENT STUDIES

1. Reflectors

The current data were obtained by photographing floating reflectors, as stated in section IIIA. These reflectors, shown on Fig. 4 (page 25) are of the type used on reflecting highway signs.

Mass produced, they are constructed of plastic surfaces, built up of many trihedral right angles, thus possessing the property of reflecting light back only to its source with remarkably little dispersion. It is for exactly this reason that they are useful on highways for nonilluminated signs. The overall diameter of the particular reflectors used are one inch with a 7/8 inch diameter reflecting surface. For our purposes two reflectors are cemented back to back to insure having a reflecting surface facing upward regardless of how they are placed on the water. When cemented together the reflectors have a total thickness of about 7/16 inch with a draft of one quarter inch.

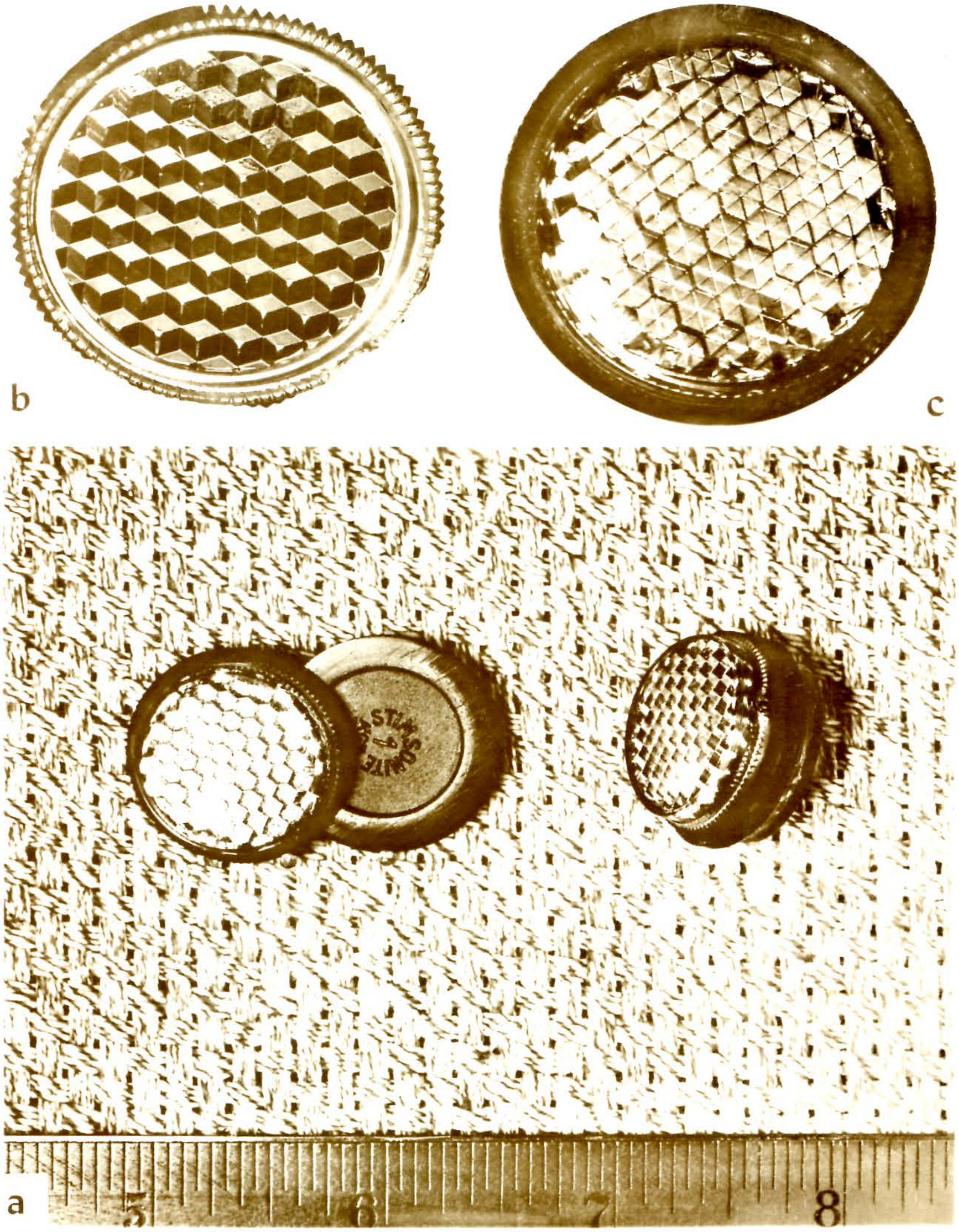
2. Camera

The movement of the reflector floats was recorded by means of a K-17 Fairchild aerial camera. It is necessary to photograph the reflections many times on the same negative. The magazine of the camera was modified therefore to prevent winding of the film between exposures by the installation of an arm on the film transport clutch to permit the disengagement of the film transport actuator. A solenoid was added by means of which the raising or lowering of the arm is accomplished electromagnetically. This modification of the camera magazine is shown on the upper half of Fig. 5 (page 29).

The camera is operated through an intervalometer with four exposures being made 10 seconds apart followed by 82 exposures four seconds apart. The time interval at the beginning is varied to indicate the direction of motion. This permits the following of the floats continuously for about 2 hours Guam time. Considerable experimentation was done with diaphragm openings and shutter speeds until satisfactory photographs were obtained finally with individual exposures at 1/300 second resulting in a total exposure of the film of 29/100 second at f/22.

Fig. 4

Fig. 4a shows two reflectors on the left ready to be cemented together to form one float as shown on the right. Because it is not possible to supply a light source near enough to the center of the camera lens in a close-up picture, the light reflection on the left reflector is rather ineffective. The scale has been included to indicate size. Fig. 4b is a view of the back of a reflector with the back membrane removed and shows the arrangement of the tri-hedral right angles. The front reflecting surface is shown in Fig. 4c. Indirect lighting, both front and rear, has been used in Fig. 4b and Fig. 4c.



Trihedral Angle Reflectors

a. Two commercial reflectors before combining to form float at right.

b. View of back of single reflector with protecting membrane removed.

c. View of reflecting surface.

Fig. 4

3. Illumination.

Considerable experimentation was also required until the most suitable illumination was obtained. Because the reflectors return light to the source very accurately lights have to be placed as near the camera as possible. At first two photoflood lights were used, mounted directly adjacent to the camera. These lights had to burn continually, and generated a great deal of heat. A greater disadvantage was that the area illuminated was not sufficiently large and that the reflectors farthest away from a vertical line through the camera did not leave readable traces on the negative.

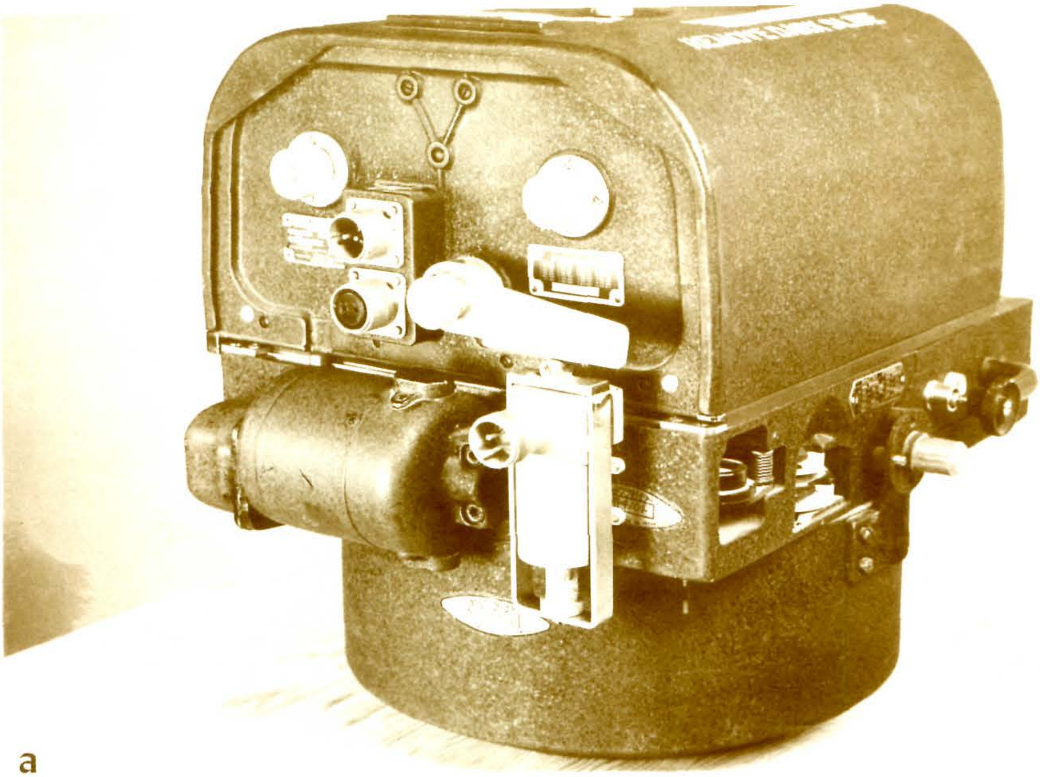
A second source of illumination, a neon tube, mounted directly on the lower edge of the camera cone was tested. This installation placed the source of light as close to the lense as possible and had the further advantage of providing fairly cool light, but the amount of illumination obtained was in - adequate.

The third and finally adopted method employs two Edgerton type flash tubes (G.E. Type FT-403) placed close to the camera. One of the lamps is shown on the lower half of Fig. 5 (page 29). These lamps are essentially the same in operation as the eight large lamps used to photograph wave patterns and described in previous reports. Power is supplied to these smaller lamps from one of the four condensers used for the large lamps. The light produced by each of the two lamps is approximately equivalent to that obtained from 2,000,000 watts

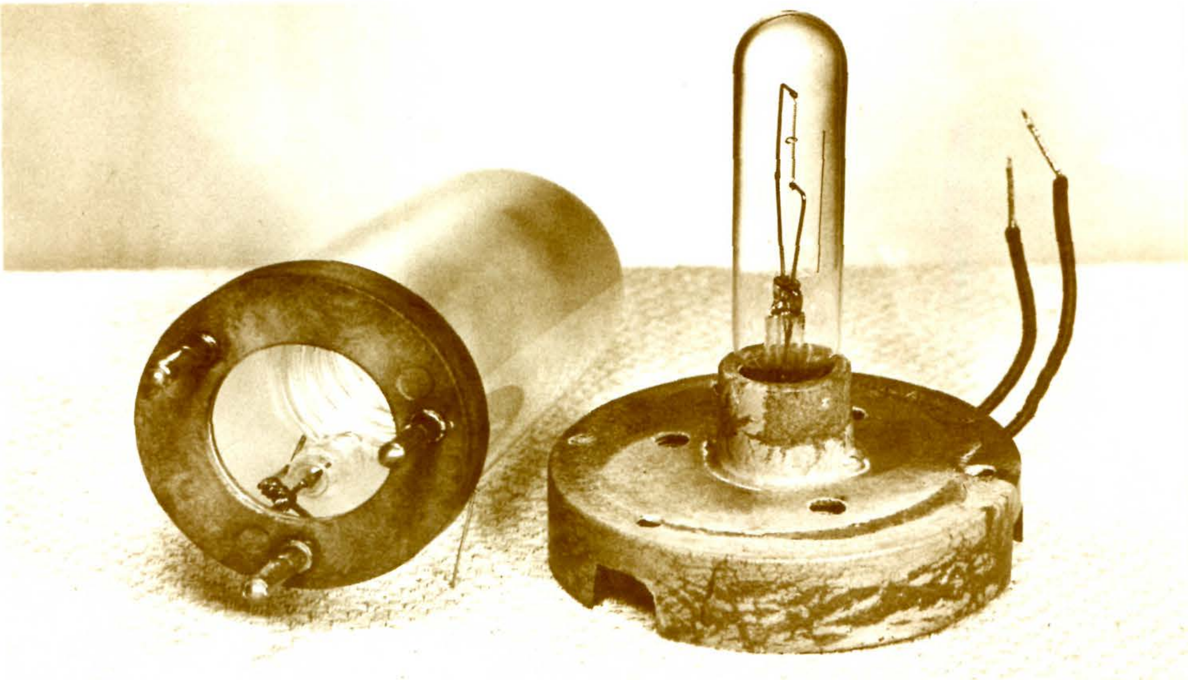
Fig. 5

The modified camera magazine used for photographing reflector floats is shown in the top half of the figure. The modification consists of the installation of an arm on the film transport clutch to permit disengagement of the film transport actuator. The solenoid has been added to assist in the arm movement.

The lower half of the figure shows one of the G.E. Type FT-403 helical flash tubes used in the current study when photographing the paths of reflector floats. The tube on the right is known as a modeling lamp. This auxiliary tube emits a continuous light to facilitate pre-run observation of float movements.



a



b

Aerial Camera And Accessories Used To Obtain Float Traces

a. K-17 aerial camera with solenoid attachment to film transport arm.

b. G. E. helical flash tube and modeling lamp, used as source of illumination for float traces.

Fig. 5

with a flash duration of 200 microseconds. These lights provide sufficient illumination to record distinct traces on the negative and at the same time permit the use of the smallest diaphragm stop combined with the shortest shutter opening, thereby minimizing the effect of undesirable daylight. Two further advantages are the absence of undue heat and the synchronization of the flash with the shutter.

E. RUN PROCEDURE

Prior to the test runs the wave machines are run for a minimum of 30 minutes, the equivalent of 9½ hours at Guam, to permit the establishment of steady state conditions before photographs are taken. The reflectors are then placed gently in prearranged positions. Upon placement of the last reflector the recording by multiple exposures of the trace of the currents is begun. This method has the disadvantage that the reflectors placed first have moved from their origins before photographing can begin. Methods are being investigated now to remedy this condition and it is anticipated that in August a system will be installed which will permit the instantaneous and simultaneous launching of all the reflectors to be used in a given run. This will be accomplished by releasing the reflectors by means of solenoids working in concert.

Each test run has a duration of six minutes, corresponding to approximately two hours at Guam.

IV MISCELLANEOUS

A. FREQUENCY RESPONSE STUDY

In order to find the natural fundamental frequency and the corresponding harmonics of each of the outer harbor, repair basin and inner harbor a series of test runs were initiated in which the magnitude of the disturbance within the basin is determined as a function of the exciting wave train. The fundamental frequency of each division of the harbor for both the longitudinal and lateral directions is first calculated.

Where the harbor floor is of uniform depth, as in the inner harbor, this calculation is a simple one. Where the depth is variable, an estimate is made of the wave celerity based on an assumed average depth. This is then checked by timing the travel of a wave across the division of the harbor concerned in the direction under consideration. The frequencies so calculated are tested first, followed by harmonics of the basic frequency and then by in-between frequencies to make the range complete. A few reasonance points have already been observed but a great deal of further study is yet to be made.

B. MARIGRAM STUDY

As mentioned in previous reports, marigrams are examined in some detail immediately upon receipt to detect any unusual or extraordinary events which might have occured. Storm periods and periods of especially active wave movements, as determined by the daily reports of Fleet Weather Central, are examined critically.

As time permits, minute differences in overall water surface elevations between the inside and the outside of the harbor are ascertained.

The marigrams of tide stations Nos. 2, 3, 4 and 5 for two lunar months in March and April 1948 were studied in this latter manner during the past month. Differences in water surface elevations between stations 3 and 2 (on opposite sides of the Piti Causeway) and between stations 5 and 4 (at Neye Island and at the extreme southerly end of the inner harbor, respectively) are read for each half hour of record. The square roots of these differences are then added algebraically in order to permit the plotting of residual mass curves showing the movement of water between stations Nos. 2 and 3, and between stations Nos. 4 and 5. A set of such curves was presented in the October 1947 report. This study is a continuing one, but additional curves will be available in a subsequent report.

C. INSTRUMENTATION

1. Oscillograph

A new motor and gearing arrangement were installed this month to give a slower and more flexible tape speed. A 2 r.p.m. telechron clock motor and associated cam were added to provide 18 sec. timing lines at 50 cycles or 15 sec. timing lines at 60 cycles.

2. Flash Tubes

Two G.E. Type FT-403 flash tubes were installed in the camera tower to provide illumination for reflector shots. The circuit of one of the condenser units ordinarily used with the large flash tubes was revised in order to permit operation of these new tubes with the equipment on hand.

3. Wave Height Averaging Device

Construction and assembly of the wave height averager is proceeding as rapidly as receipt of component parts will allow. It is anticipated that the unit will be completed and in operation about the middle of September.